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# SUSTAINED FLIGHT OPERATIONS IN NAVY P-3 AIRCRAFT

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Flight crew fatigue during sustained flight operations (SUSOPS) is an important aeromedical problem. We evaluated the effects of SUSOPS on aircrew stress and fatigue in three U.S. Navy P-3 Orion crews (n = 21) before, during, and after a 6-month overseas deployment. Pre- and postdeployment laboratory tests measured aerobic capacity, pulmonary function, muscular strength and endurance, and resting blood chemistry. Postdeployment lung capacity, blood chemistry values, grip strength, and leg endurance all improved while leg strength, aerobic capacity, and percentage body fat decreased. During deployment, we collected inflight urine samples and subjective fatigue and positive/negative mood surveys hourly. Urinary sodium and potassium levels were significantly higher inflight compared to postdeployment control values. Urinary norepinephrine concentrations inflight were lower compared to controls. Subjective-fatigue scores decreased from preflight to postflight. Positive mood scores decreased while negative mood scores increased. Subjects showed varying levels of stress and fatigue, which did not appear to compromise performance and safety. The 15-h nonflying intervals between flights provided sufficient rest for the crews. Keywords:

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## SUMMARY PAGE

### THE PROBLEM

The influence of sustained flight operations (SUSOPS) on flight crew fatigue is an important aeromedical consideration. Flight crew fatigue affects mission performance and is often a contributing factor in aircraft accidents. The purpose of this study was to evaluate the effects of anti-submarine warfare (ASW) SUSOPS on crew stress and fatigue in three U.S. Navy P-3 Orion crews ($n$ = 21). Pre- and postdeployment physiological tests performed in the laboratory on all crew members included assessment of aerobic capacity, pulmonary function, muscular strength and endurance, and resting blood chemistry. During deployment, inflight urine samples were collected on the 3 crews over 11 flights. Additionally, subjective fatigue and positive/negative mood surveys were completed hourly inflight by all crew members. Grip strength was also measured hourly inflight.

### FINDINGS

Urinary sodium and potassium levels were significantly higher inflight compared to postdeployment control urine values. Urinary norepinephrine concentrations inflight were lower when compared to control values. Subjective fatigue scores showed decreasing fatigue from preflight to postflight. Positive mood scores decreased while negative mood scores increased on the average over 10 flights. Grip-strength measurements were inconsistent and erratic showing no trends in changes over each flight.

Following the 6-month deployment, aerobic capacity decreased, lung capacity improved, blood-chemistry values increased, grip strength increased, leg strength decreased while leg endurance increased, and percentage body fat decreased.

Subjects completing 12-h SUSOPS ASW missions during a 6-month overseas deployment showed varying levels of stress and fatigue, which did not appear to compromise performance and safety. The 15-h nonflying intervals between flights appeared sufficient to minimize stress on the crews.

### RECOMMENDATIONS

We recommend that future investigations of ASW SUSOPS in the patrol community include sleep surveys, body temperature monitoring, and crew task-performance assessment, which were not addressed in this study. When considered with the physiological and psychological parameters that we evaluated, additional research may yield answers to the problems of how to better define and measure fatigue, performance, and the effect of fatigue on performance. Sacrificing the completion of a mission because of crew fatigue is not always a viable alternative, but future research may lead to methods for reducing the effects of fatigue on flight performance in sustained operations.

## Acknowledgments

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# INTRODUCTION

The influence of sustained flight operations (SUSOPS) on flight crew fatigue is an important aeromedical consideration. Flight crew fatigue affects mission performance and is often a contributing factor in aircraft accidents. A study of Aviation Safety Reports found that fatigue caused significant performance decrements related to time of day, awareness, attention to duty, and the final phases of flight (1). Further, most of the fatigue-related incidents involved altitude deviations, and takeoffs and landings without clearance. These fatigue-associated lapses in pilot performance resulted in potentially unsafe conditions.

Estimates of fatigue as a cumulative factor in military aviation accidents vary according to the source. While a U.S. Army study estimated that fatigue contributed to 10.5% of all aircraft accidents from 1964 to 1972 (2), a U.S. Navy report found fatigue to be a factor in 20.4% of all P-3 aircraft mishaps from 1969 through 1985 (3). Another survey of major P-3 aircraft accidents showed that fatigue was a contributing factor in 50% of all accidents from 1962 to 1969 (4).

In 1982, the Chief of Naval Operations issued a requirement to investigate the problem of fatigues in the Navy's patrol community. The guidance stated a need to determine whether fatigue existed, define it, quantify it, and measure its effects on flight and mission performance. Additionally, a medical requirement from the fleet prompted a question on the validity of current Navy requlations for work/rest cycles, i.e., 12 hours work/15 hours rest, during extended flight operations.

Several alternatives are available to study the problem of crew fatigue during SUSOPS. Physiologic analyses have focused on endocrine-metabolic assays of urine samples. The availability of urine samples and the large number of pertinent metabolites excreted make urinalysis a viable means of studying the biochemical processes accompanying physical and mental work as well as psychological stress. Many researchers have used urinary metabolites to study stress and fatigue during SUSOPS (5-16). In a study of long-range flights in C-5 and C-141 aircraft, crew performance did not decline even though urinary metabolites changed significantly with flight time (8). The high values for catecholamines and 17-hydroxycorticosteroid (17-OHCS) were interpreted as a compensatory response t... contributed to the maintenance of psychomotor performance. The explanation was that the reticular activating system, when responding to environmental stimuli, indirectly activates the sympathoadrenomedullary and adrenocortical systems. These systems, in turn, provide feedback to the reticular system.

Another study reported a rough, nonstatistical comparison between stress and performance (7). A stress index was computed as the average deviation of 11 urinary variables measured inflight and compared to a control situation. A performance index was computed as the percentage of deviation from a previous 6-month average of flight scores. The subjects were assigned arbitrarily to superior or inferior performance groups based on their flight proficiency scores. The superior group performed better as stress increased. In contrast, performance of the inferior group declined as stress increased. The higher stress index of the inferior group resulted primarily from greater deviations in the endocrine-metabolic responses of the norepinephrine: epinephrine ratio (NOREPI:EPI), phosphate (P), sodium (Na), and the sodium:

potassium ratio (Na:K) measured in the urine. A later review attributed large individual variation in the magnitude and the direction of urinary metabolite responses to stress (18). Such individual differences obfuscate a consistent relationship between urinary metabolites and fatigue.

Several investigators have used psychological analyses with subjective fatigue and mood to study fatigue on long-duration flights (12,18-23). One study used the Profile of Mood States (POMS) questionnaire to evaluate mood changes in a 6-day SUSOPS study with partial sleep deprivation (20). The author found that mood scores during sleep-deprived days were significantly lower than baseline scores. In a study on the effects of total sleep deprivation during a 54-h period, the authors used the U.S. Naval Health Research Center (NHRC) Mood Scale and found a significant decrease in positive mood and a significant increase in negative mood with time (18). A report (19) on the effects of moderate physical work on mood and performance showed a 50% increase in negative mood using both the POMS and the NHRC Mood Scale.

Results of SUSOPS studies employing subjective fatigue vary. Subjective fatigue was measured using the USAF School of Aerospace Medicine Subjective Fatigue Checklist (SAM Form 136) in a 30-h extended mission aboard an Air Force E-4B aircraft (16). During the mission, subjective fatigue levels were moderate and not high enough to compromise performance or safety. On the afternoon and the evening following the mission, however, severe levels of fatigue were reported. In a study of crew fatigue in nonstop transoceanic flights in tactical aircraft, mild levels of subjective fatigue did not cause performance to decrease (23). Other studies have reported significant levels of subjective fatigue on long-duration missions. For example, subjects became progressively more fatigued over a 54-h period of wakefulness as indicated by their significantly lower scores (18). Similarly, subjective fatigue increased significantly over two 20-h continuous work episodes as measured by the POMS fatigue subscale and the SAM Fatigue Checklist (19).

Although various measures before, during, and after SUSOPS have been studied intensively, the physiological response or "cost" of stress-induced fatigue due to long-duration flights has not been reported. We found no literature on the effects of SUSOPS on oxygen uptake, pulmonary function, substrate utilization, and muscular strength and endurance, although one paper does discuss the oral temperature response of USAF C-5 aircrewmen during long cargo missions as a physiologic result of fatigue (22). Our approach was to obtain muscular strength (hand grip) measurements, urine samples, subjective fatigue, and subjective mood inflight to examine the physiologic cost of fatigue during long flights. We investigated the effects of SUSOPS on stress and fatigue in three U.S. Navy P-3 Orion crews. We used a multiphased, multidisciplinary approach to define fatigue and to quantify the stressful effects of long-duration ASW missions.

## METHODS

Three different crews flying ASW missions in P-3 Orion aircraft during overseas deployments were used in this study. Thirty-three crew members flew 11 missions over 6 weeks while inflight data were collected. Two crews flew four missions each, and the third crew flew three missions. Missions were 9-15 h (mean = 12.6 h) from preflight to postflight. Takeoff times for each sortie were scheduled by operational needs for night or day with no consistency or control for circadian rhythm. All flights were defined according to the

tasks of the crew and the sequence of the mission: 1) preflight, 2) transit flight to the area of operation, 3) on station, 4) transit flight back to the base, and 5) postflight (Table 1).

TABLE 1. Inclusive Military Times for Phases of each Mission.

| Crew | Flight | 1-Pre flt | 2-Transit | 3-On station | 4-Transit | 5-Post flt |
|---|---|---|---|---|---|---|
| 1 | 1 | 0100-0300 | 0400-0500 | 0600-1200 | 1300 | 1400-1500 |
| | 2 | 0600-0800 | 0900-1100 | 1200-1600 | 1700-1800 | 1900-2000 |
| | 3 | 0700-0800 | 0900-1100 | 1200-1700 | 1800-1900 | 2000-2100 |
| | 4 | 0900-1100 | 1200-1300 | 1400-1800 | 1900-2000 | 2100-2200 |
| 2 | 1 | 0400-0600 | 0700-0800 | 0900-1300 | 1400-1500 | 1600-1800 |
| | 2 | 0500-0900 | 1000-1200 | 1300-1400 | 1500-1600 | 1700-1800 |
| | 3 | 0700 | 0800-0900 | 1000-1200 | 1300-1400 | 1500-1600 |
| | 4 | 0700-0900 | 1000 | 1100-1200 | 1300 | 1400-1700 |
| 3 | 1 | 1000-1300 | 1400-1600 | 1700-2100 | 2200-2300 | 2400-0100 |
| | 2 | 1100-1500 | 1600-1700 | 1800-2200 | 2200 | 2300-0100 |
| | 3 | 1800-2000 | 2100 | 2200-0400 | 0400 | 0500-0600 |

Normal ASW tasks were performed during all missions. Each crew contained 11 personnel performing different jobs: flying, navigating, detecting and tracking submarines, and operating communications and radar systems. The average age of crew members was 26.1 years, and their ASW flight experience ranged from 0 to 3500 h (average 1140 h) as shown in Table 2.

TABLE 2. Descriptive Characteristics of Subjects (Mean ± SD).

| Crew | n | Age (yr) | Height (cm) | Weight (kg) | ASW flight time (h) |
|---|---|---|---|---|---|
| 1 | 9 | 26.6 ± 3.8 | 176.1 ± 6.0 | 82.4 ± 9.8 | 1100 ± 990 |
| 2 | 8 | 27.5 ± 5.8 | 180.2 ± 7.1 | 82.6 ± 10.6 | 1600 ± 1400 |
| 3 | 4 | 25.4 ± 5.5 | 176.7 ± 5.7 | 75.7 ± 8.4 | 850 ± 840 |

## LABORATORY PRE/POSTDEPLOYMENT

All crew members underwent physiological testing 1 month before and within 2 months after their 6-month overseas deployment. These tests were used to determine fitness levels and to identify significant changes in fitness during deployment that may have affected fatigue during SUSOPS. The physiological test battery assessed maximal aerobic capacity, pulmonary function, body composition, muscular strength and endurance, and resting blood chemistry. Resting heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) were measured in conjunction with a routine physical examination prior to any testing. All testing occurred over an entire week to eliminate any test overlap or bias and to allow for full recovery between tests.

The aerobic capacity test was performed on a motorized treadmill (Quinton Model 65, Seattle, WA) using the Bruce protocol (24), which gradually increased speed and elevation until a maximal oxygen consumption ($VO_2$ max) plateau was achieved. An MMC Horizon Metabolic Cart (Beckman Instruments, Anaheim, CA) was used to determine oxygen and carbon dioxide concentrations of expired air during the test. Blood pressure was measured using a Critikon automatic cuff (Model 1165, Tampa, FL), and HR and 16-lead electrocardiogram were recorded with a Quinton Model 2000 Exercise Monitor (Seattle, WA) before, during, and after the stress test.

A standard pulmonary function test (25) was performed (Jaeger Pneumoscreen II, Germany) to assess lung flow and volume characteristics. Vital capacity (VC), forced vital capacity (FVC), peak flow (PF), residual volume (RV), and forced expiratory volume at 1 s (FEV1) were measured.

Body composition was determined using a skinfold caliper (Quinton, Seattle, WA) using the procedure reported by Jackson and Pollock (26). Skin and subcutaneous fatfolds were measured at seven different sites on the body.

Cybex II (Luminex, Ronkonkoma, NY) muscle testing equipment was used to evaluate muscular strength and endurance (27). Force, or torque, produced during maximal voluntary isokinetic contractions was recorded on five right-knee extensions at a slow speed of $60^{o}$ per second. Muscular endurance was measured as the total work on 50 rapid, right-knee extensions at $180^{o}$ per second. Grip strength of both hands was determined using a Jaymar (Asimov, Santa Monica, CA) dynamometer (28). The best score of three trials was used.

Routine resting blood chemistry analysis was performed on two 20-ml venous samples drawn from the antecubital site before the exercise stress test. Assays of serum lipoproteins, triglycerides, electrolytes, glucose, and isoenzymes were performed to quantify the physiological status of all subjects (29).

DEPLOYMENT

During deployment, urine samples were acquired inflight from all crew members at each urination during each mission phase. Each urine sample was collected in a sterile glass tube, acidified, labeled, and frozen until analysis at the Naval Aerospace Medical Research Laboratory. Epinephrine, NOREPI, 17-OHCS, creatinine (CRE), Na, K, urea (U), and urine volume were identified quantitatively. Samples were preserved by acidification ($<$ pH 3) or by the addition of boric acid (0.8 g/100 ml of urine) and stored frozen at -20 $^{o}$C until assayed. All analyses were run in duplicate or greater replication, and the mean of replicate determinations was reported.

Sodium and K levels were determined using commercially available reagents, spectrophotometric techniques, and an automated chemistry analyzer (Baker Instruments, Allentown, PA). Urinary 17-OHCS was analyzed by the Porter and Silber method (30) as defined by Sunderman (31). Catecholamines were measured by high-performance liquid chromatography (HPLC) with electrochemical detection (Bioanalytical Systems, West Lafayette, IN) as described elsewhere (32).

We attempted to record grip strength, subjective fatigue, and positive and negative mood hourly inflight. Subjective positive- and negative-mood questionnaires (Fig. 1) and subjective-fatigue forms (Fig. 2) were distributed hourly during each flight to all crew members. The mood instruments assessed how subjects felt at that particular moment. The self-rating subjective fatigue form required minimal time to complete and resulted in scores ranging from 0 to 20 with lower scores indicating greater fatigue.

Right- and left-hand grip-strength measurements were attempted hourly inflight on all crew members following the procedure described above. Although subjects were cooperative during this phase of the study, the intense nature of some mission functions precluded the collection of inflight data. We did, however, attempt to adhere to the hourly schedule of gathering the subjective and grip-strength data without interfering with the crews' tasks.

CONTROL

All three crews were retested to obtain control data 1-2 months following deployment. At this time, all crew members had returned to their normal squadron duties stateside and their homelife routine. During this phase, each crew member provided a sample from each urination within a 24-h period. The samples were treated and analyzed as described above. Control and inflight values were compared by matching time-of-day groupings, that is, samples drawn during preflight time during deployment were compared to samples from the same time of day during the control phase.

DATA ANALYSIS

Pre- and postdeployment physiological data were compared with paired sample $t$ tests at $p < .05$. Twenty-one of 33 crew members completed both phases of the physiological testing. Inflight urine data were grouped by crews into the five segments of each mission. Means from each segment were compared to control values from equivalent time periods with $t$ tests. Individual inflight and control urine samples, as well as positive and negative mood, subjective fatigue, and grip strength were analyzed across flight times, comparing means for each of the five segments of the flights.

## RESULTS

LABORATORY PRE/POSTDEPLOYMENT

Mean pre- and postdeployment physiological testing results are presented in Table 3. Resting HR decreased significantly ($p < .01$) following deployment. Although both resting SBP and DBP increased following deployment, only DBP changed significantly ($p < .05$). Body weight increased during the 6-month deployment while percentage body fat decreased 2.5% ($p < .05$), indicating an increase in lean body mass.

Aerobic capacity test results indicated an overall decrease in cardiorespiratory fitness. Only maximal HR ($p < .01$) and treadmill time ($p < .05$) decreased significantly. The remaining tests, maximal SBP, DBP, $VO_2$ max, and minute ventilation (VE), decreased, but not significantly, following deployment. The respiratory quotient (RQ) was the only value that increased. Of the pulmonary function tests, VC increased significantly $p < .01$), and FVC and FEV1 tended to increase. The RV and peak flow both decreased.

MOOD CHECKLIST

TIME:

NAME: ______________________

POSITION: ______________________

| | NOT AT ALL | A LITTLE | MODER-ATELY | QUITE A BIT | EXTREMELY |
|---|---|---|---|---|---|
| ACTIVE | 0 | 1 | 2 | 3 | 4 |
| VIGILANT | 0 | 1 | 2 | 3 | 4 |
| ANNOYED | 0 | 1 | 2 | 3 | 4 |
| CAREFREE | 0 | 1 | 2 | 3 | 4 |
| CHEERFUL | 0 | 1 | 2 | 3 | 4 |
| CONSIDERATE | 0 | 1 | 2 | 3 | 4 |
| DEFIANT | 0 | 1 | 2 | 3 | 4 |
| DEPENDABLE | 0 | 1 | 2 | 3 | 4 |
| SLEEPY | 0 | 1 | 2 | 3 | 4 |
| DULL | 0 | 1 | 2 | 3 | 4 |
| EFFICIENT | 0 | 1 | 2 | 3 | 4 |
| FRIENDLY | 0 | 1 | 2 | 3 | 4 |
| FULL OF PEP | 0 | 1 | 2 | 3 | 4 |
| GROUCHY | 0 | 1 | 2 | 3 | 4 |
| HAPPY | 0 | 1 | 2 | 3 | 4 |
| JITTERY | 0 | 1 | 2 | 3 | 4 |
| KIND | 0 | 1 | 2 | 3 | 4 |
| LIVELY | 0 | 1 | 2 | 3 | 4 |
| PLEASANT | 0 | 1 | 2 | 3 | 4 |
| RELAXED | 0 | 1 | 2 | 3 | 4 |
| FORGETFUL | 0 | 1 | 2 | 3 | 4 |
| SLUGGISH | 0 | 1 | 2 | 3 | 4 |
| TENSE | 0 | 1 | 2 | 3 | 4 |
| CLEAR THINKING | 0 | 1 | 2 | 3 | 4 |
| TIRED | 0 | 1 | 2 | 3 | 4 |
| HARD WORKING | 0 | 1 | 2 | 3 | 4 |

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Figure 1. Mood checklist.

## SUBJECTIVE FATIGUE CHECKLIST

| SUBJECTIVE FATIGUE CHECKLIST | | DATE |
|---|---|---|
| SOCIAL SECURITY NUMBER | NAME *(Last, First, MI)* | CODE OR CASE NR. |
| RANK | TEST IDENTIFICATION | |

INSTRUCTIONS: Make one, and only one ( ✓ ) for each of the ten items. Think carefully about how you feel right now.

| ITEM NR. | BETTER THAN | SAME AS | WORSE THAN | STATEMENT |
|---|---|---|---|---|
| 1. | | | | VERY LIVELY |
| 2. | | | | EXTREMELY TIRED |
| 3. | | | | QUITE FRESH |
| 4. | | | | SLIGHTLY POOPED |
| 5. | | | | EXTREMELY PEPPY |
| 6. | | | | SOMEWHAT FRESH |
| 7. | | | | PETERED OUT |
| 8. | | | | VERY REFRESHED |
| 9. | | | | FAIRLY WELL POOPED |
| 10. | | | | READY TO DROP |

REMARKS

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Figure 2. Subjective fatigue checklist.

Changes in muscular strength and endurance measurements were not significant, although tendencies to increase or decrease appeared contradictory. Both right- and left-hand-grip strengths increased, but right-knee-extension tests of isokinetic strength decreased at 60° per second, while right-knee extension endurance, measured as total work, increased on the 50 repetition test at 180° per second.

TABLE 3. Pre- and Postdeployment Physiological Measurements (Mean ± SD) in 21 Subjects.

| Variable | Predeployment | Postdeployment |
|---|---|---|
| **Descriptive** | | |
| Body fat (%) | 16.9 ± 6.1 | 14.3 ± 5.2* |
| Rest SBP (mm Hg) | 122.0 ± 8.3 | 125.7 ± 10.3 |
| Rest DBP (mm Hg) | 71.4 ± 8.0 | 77.9 ± 10.0* |
| Rest HR (bpm) | 79.4 ± 10.9 | 70.9 ± 11.7** |
| **Aerobic capacity** | | |
| HR max (bpm) | 202.5 ± 7.7 | 196.9 ± 9.3** |
| SBP max (mm Hg) | 213.1 ± 16.0 | 197.1 ± 49.8 |
| DBP max (mm Hg) | 84.4 ± 15.3 | 82.9 ± 14.1 |
| $VO_2$ max (ml/kg/min) | 47.6 ± 9.1 | 45.6 ± 9.4 |
| METS max | 13.6 ± 2.6 | 13.1 ± 2.7 |
| Treadmill time (min) | 13.9 ± 2.4 | 13.1 ± 2.5* |
| $V_E$ max (L/min) | 149.9 ± 20.7 | 142.7 ± 24.7 |
| **Pulmonary function** | | |
| Vital capacity (L) | 5.07 ± 0.79 | 5.85 ± 0.67** |
| FVC (L) | 5.77 ± 0.70 | 5.99 ± 0.66 |
| FEV1 (L) | 4.50 ± 0.51 | 4.52 ± 0.65 |
| Peak flow (L/s) | 11.62 ± 2.10 | 11.00 ± 1.61 |
| RV (L) | 1.71 ± 0.45 | 1.71 ± 0.40 |
| **Muscular strength** | | |
| Grip strength, right hand (kg) | 50.9 ± 8.7 | 58.6 ± 9.9 |
| Peak torque, right knee[a] | 197.0 ± 40.2 | 178.1 ± 46.8 |
| Total work, right knee ext[b] | 1124.6 ± 148.3 | 1147.9 ± 190.7 |
| **Blood chemistry** | | |
| Total cholesterol (mg %) | 176.0 ± 33.8 | 199.9 ± 30.4** |
| HDL cholesterol (mg %) | 44.2 ± 16.5 | 47.3 ± 10.3 |
| Triglycerides (mg %) | 145.3 ± 57.1 | 144.5 ± 74.7 |
| Glucose (mg %) | 98.7 ± 11.7 | 121.8 ± 28.3** |
| Hematocrit (%) | 44.2 ± 2.7 | 46.5 ± 3.4* |
| Hemoglobin (g/100 ml) | 15.0 ± 2.3 | 16.5 ± 0.7** |

[a]@60 °/s (Nm). [b]@180 °/s, reps (J).
* $p \leq .05$. ** $p \leq .01$.

All blood chemistry values increased during postdeployment. Total cholesterol, glucose, and hemoglobin were significant ($p < .01$), as well as hematocrit ($p < .05$).

## DEPLOYMENT

Inflight urine samples proved difficult to collect, ship, analyze, and interpret. Only Na, K, CRE, and NOREPI were present in sufficient quantities for analysis. Urinary Na, K, and the Na:K ratio tended to increase during each mission, peaking during the on-station phase and returning close to initial preflight levels during postflight (Figs. 3,4,5, respectively).

This phenomenon also occurred for the mean inflight urine electrolytes of all crew members over all 11 flights (Fig. 6). We found significant differences ($p < .05$) between inflight and control Na and K means (Table 4). Both constituents were elevated during the inflight deployment period. Urinary NOREPI concentrations decreased significantly ($p < .05$) inflight (Table 4), indicating a suppressed sympathoadrenomedullary response during missions. Unfortunately, EPI and 17-OHCS were not present in sufficient quantities for analyses.

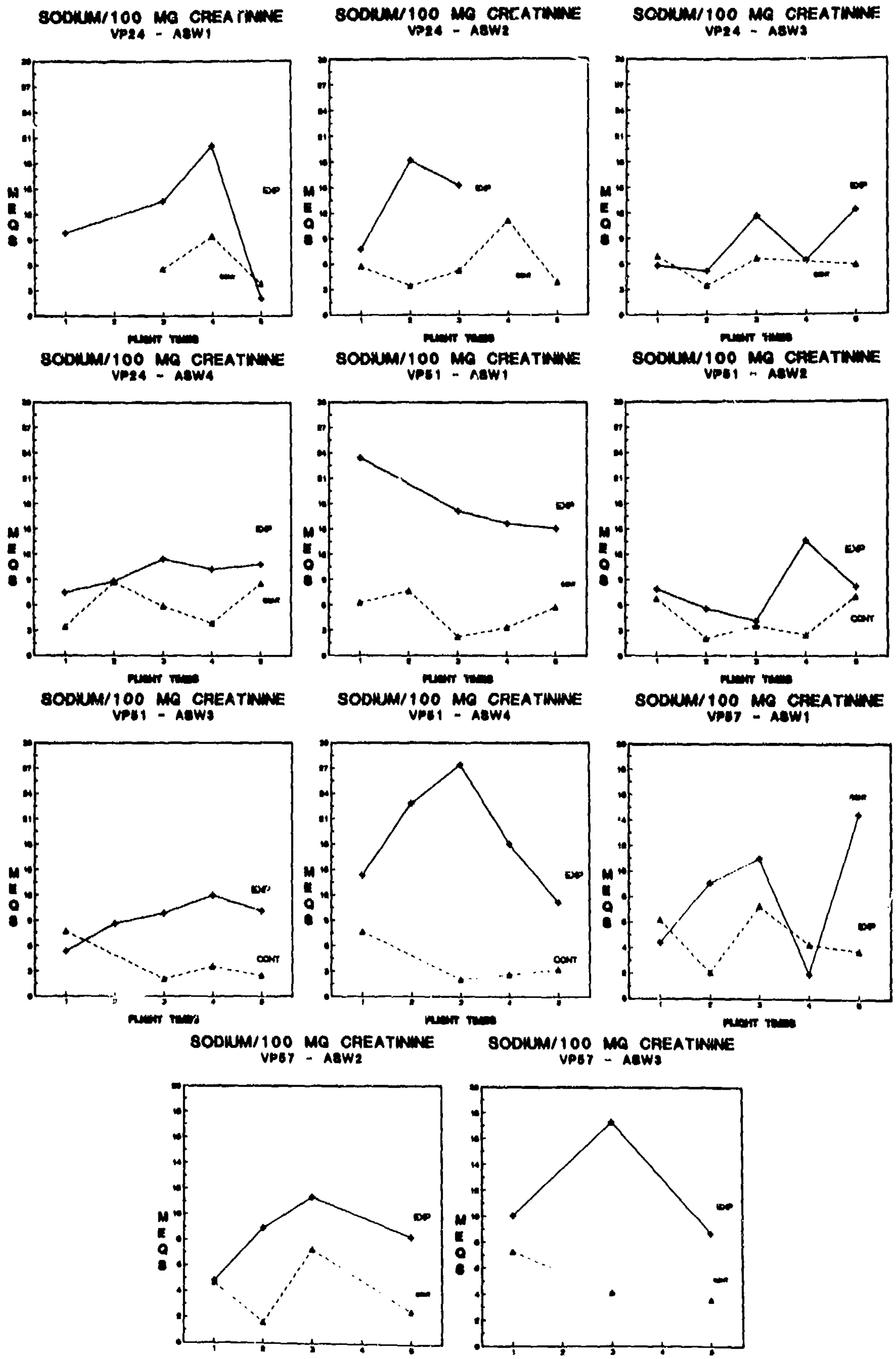
TABLE 4. Mean (± SD) of Urinary Variables Inflight.

| Variable | n | Inflight | Control | t test |
|---|---|---|---|---|
| Sodium (meq/100 mg Creat.) | 25 | 12.3 ± 1.45 | 5.6 ± 0.79 | $p = .004$ |
| Potassium (meq/100 mg Creat.) | 25 | 3.1 ± 0.46 | 1.9 ± 0.24 | $p = .048$ |
| Sodium:potassium ratio | 24 | 4.79 ± 0.55 | 3.71 ± 0.40 | $p = .12$ |
| Norepinephrine (mg) | 20 | 2.23 ± 1.16 | 3.61 ± 2.00 | $p = .017$ |

The nature and intensity of the work performed during a mission prevented some crew members from completing the subjective-fatigue form. Nonetheless, in almost all cases, subjective fatigue decreased steadily from preflight to postflight (Fig. 7). Subjective fatigue scores recorded inflight can be evaluated as relative or absolute values. Our scoring was as follows: ≤ 7, severe fatigue; 8-11, moderate fatigue; and ≥ 12, alertness. All crews reported lower scores, bordering on severe fatigue during the preflight phase. On-station mean scores ranged from severe to moderate fatigue. Postflight subjective fatigue showed the most variability ranging from severe fatigue to feelings of alertness.

Self-assessments of positive and negative moods indicated current affective states: higher scores reflected greater affective states. In otherwords, a high positive-mood score indicated a trend towards a positive attitude, while a high negative score indicated a greater negative attitude. The overall trend was decreasing positive moods and increasing negative moods (Fig. 8).

Muscular grip-strength measurements inflight were inconsistent (Fig. 9). Mean scores varied considerably at all times and showed no trends over 10 flights. Strength between crews, within crews across time, and within crews between flights changed erratically.




* Flight times represent: (1) Preflight; (2) Transit; (3) On station; (4) Transit; (5) Postflight

Figure 3. Urinary sodium concentrations during missions.

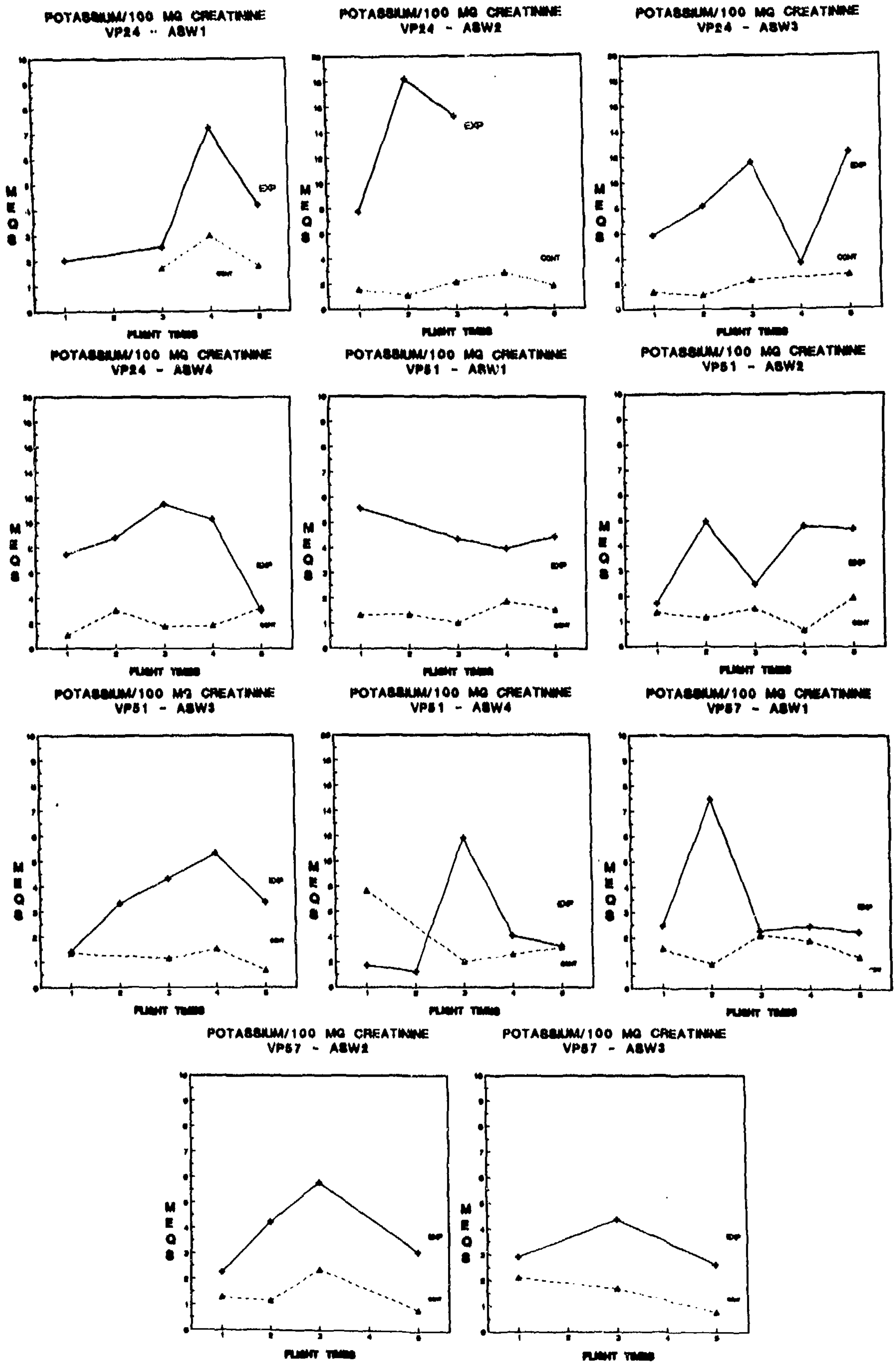



Figure 4. Urinary potassium concentrations during missions.

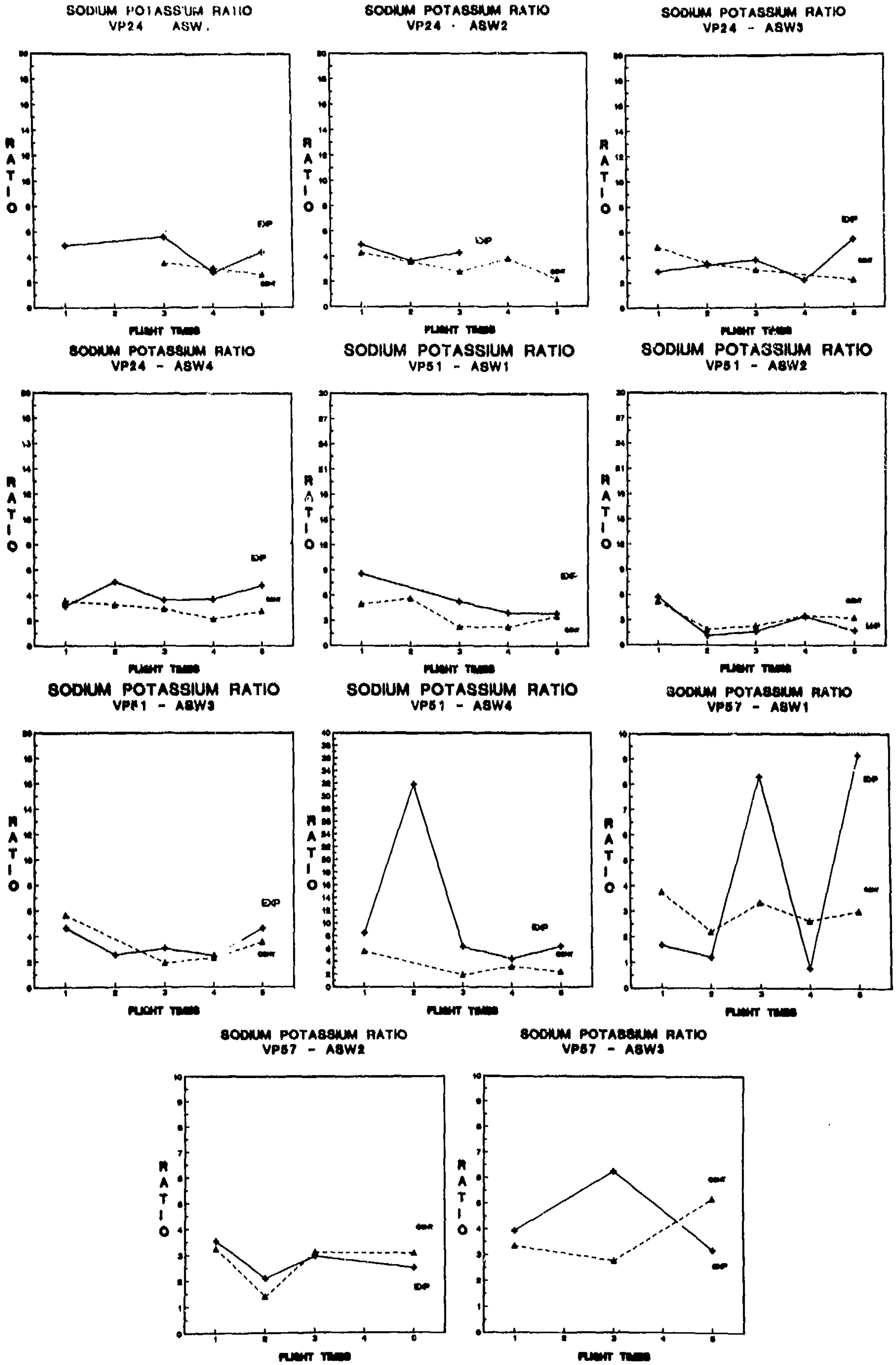



Figure 5. Urinary sodium:potassium ratios during missions.

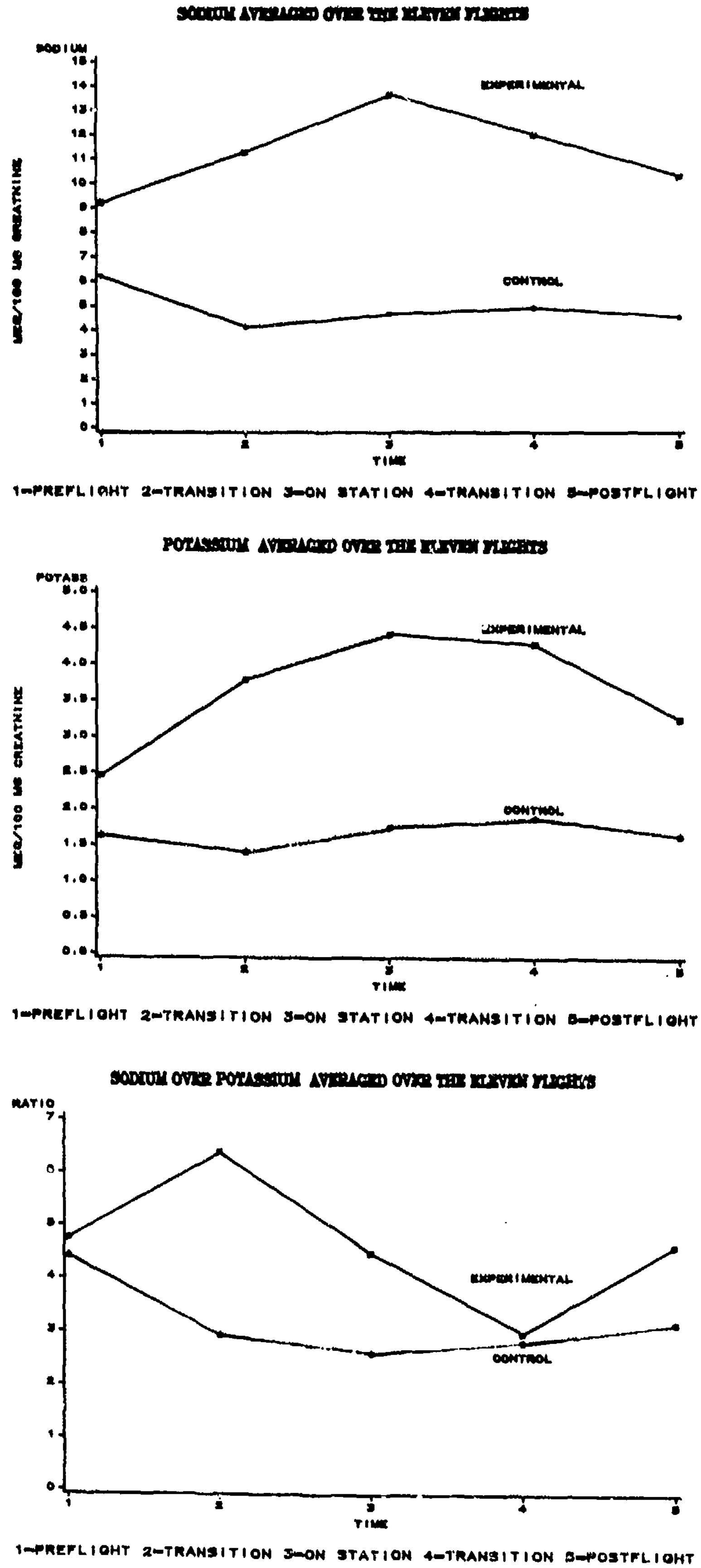



Figure 6. Urinary sodium, potassium, and sodium:potassium ratios over all flights.

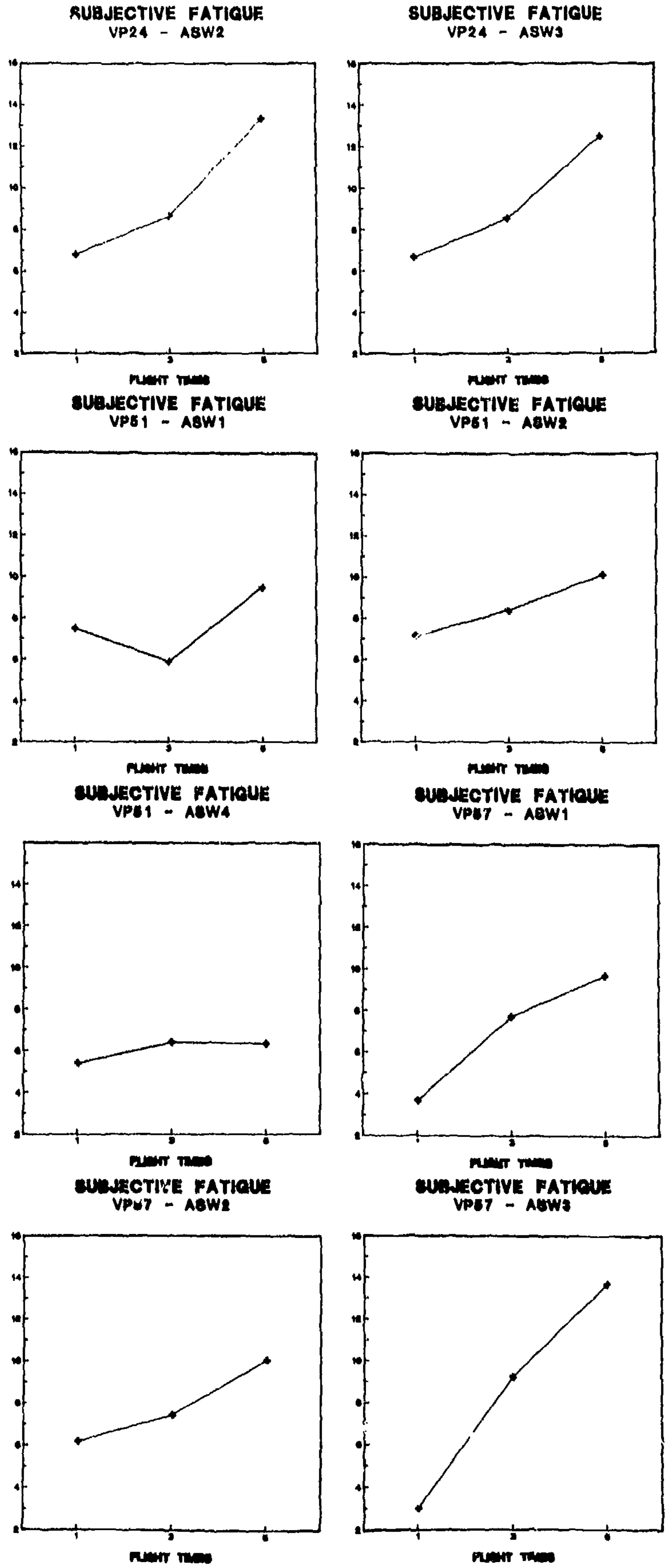



Figure 7. Subjective fatigue scores during missions.

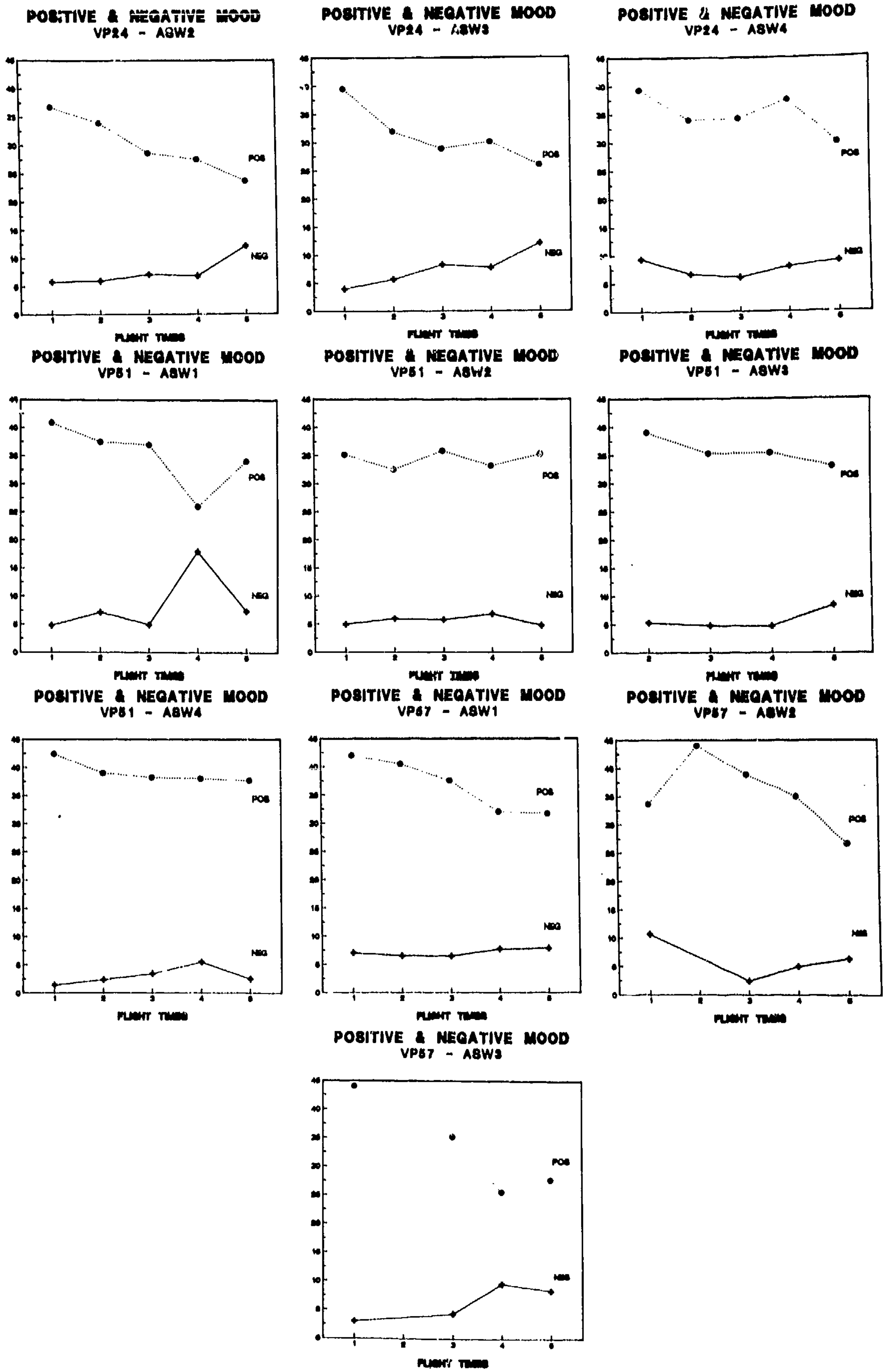



Figure 8. Positive and negative mood scores during missions.

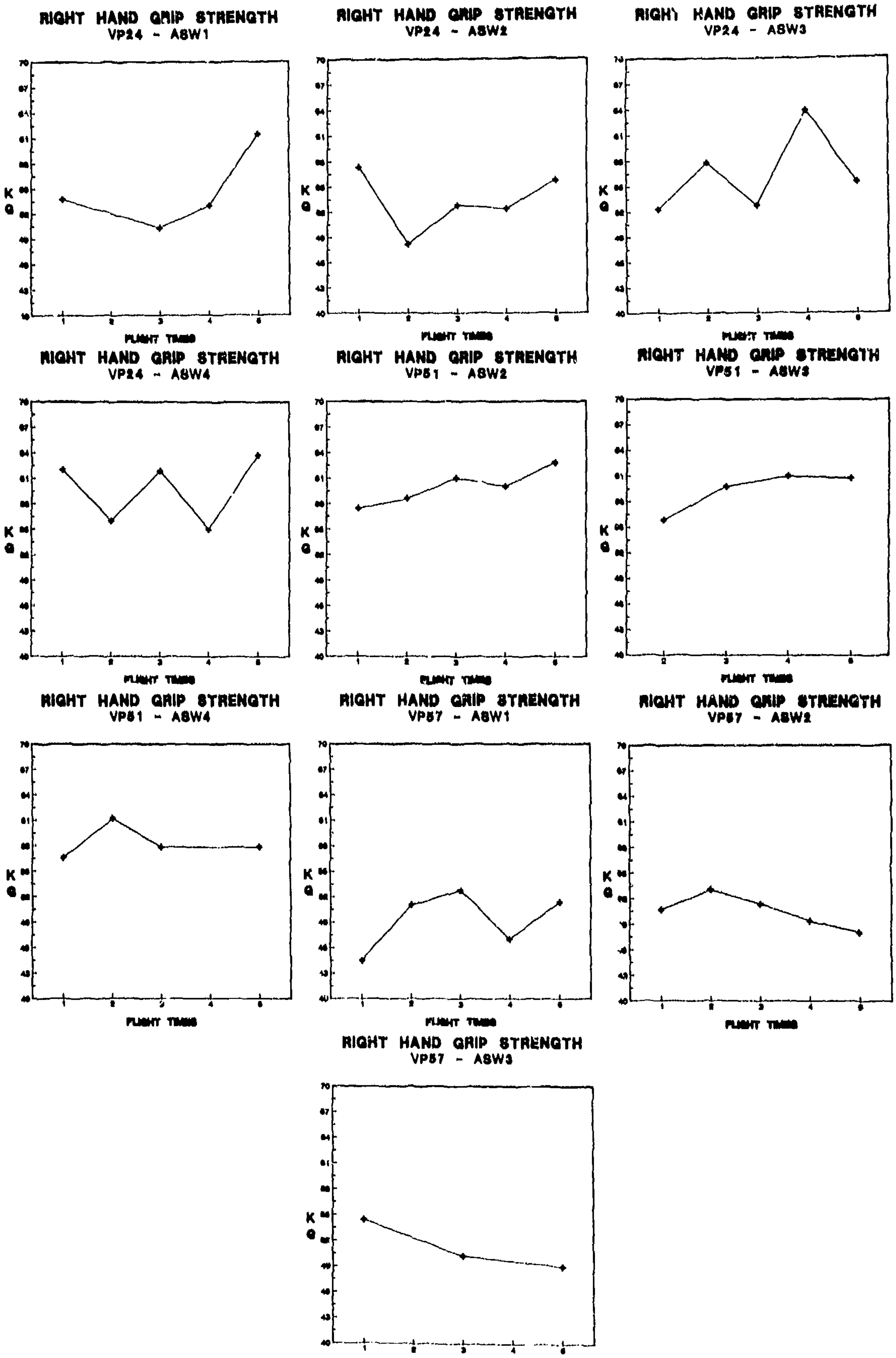



Figure 9. Grip strength during missions.

## DISCUSSION

During overseas deployment, U.S. Navy P-3 crew members are isolated from their homes and usual routines. Their primary mission is to fly ASW sorties against Soviet ships, but they must also continue their normal complement of squadron duties, which can be very demanding. Each sortie is unique but follows a distinct pattern: preflight; transit flight to the area of operation; flight on-station to find, monitor, and prosecute enemy submarines; transit back to the base; and postflight, which conveniently allows for comparisons between and among flights. Even though current naval regulations dictate a 15-h off/12-h on work-rest cycle for extended ASW operations, cumulative fatigue is quite possible. One of the more difficult problems in SUSOPS research has been to distinguish among the effects of chronic, acute, and cumulative fatigue. In our study, lower preflight scores were not caused by the fatigue of the mission. One can only speculate on the possibility of cumulative fatigue from previous missions affecting performance.

Inflight data collection proved more difficult than anticipated, even though all crew members participated enthusiastically. Collection of inflight urine samples was "as necessary" whenever a crew member needed to void. Urinary volumes and metabolite concentrations were probably affected by the unrecorded ingestion of food and fluids before and during each flight. In the future, we recommend that diaries of food and fluid intake be kept when feasible.

Changes in the urinary biochemical measurements may have also occurred from psychological or biological demands on crew members. In fact, all operational stresses (noise, vibration, altitude, temperature, task, *et cetera*) induce or contribute to fatigue during long flights (33). Urinary metabolites have been used to indicate long-duration flight stress and to define crew fatigue in a number of studies of varying duration (6,8-11,14,16,34) with different aircraft on different missions (5,12,13,21,22). Our study concurs with others in endocrine-metabolic responses during SUSOPS that report intersubject variability due to situational differences. Despite possible temporary electrolyte imbalances inflight due to the mission stress, in most cases, the Na:K ratio, an index of homeostatic mineral metabolic activity, tended towards stability. Inflight Na and K increased and tended to peak during the more intense on-station flight phase before dropping to near-preflight levels indicating greater metabolic activity.

Sympathetic adrenal activity in this study contradicted earlier reports of increased urinary NOREPI concentrations during and after long flights (5,6,9-11,16,22). One possible explanation for our observed catecholamine reversal may be that deployment is not always a particularly stressful environment. That is, much of the flying becomes routine to well-trained crews. Although crew members perform intensely arduous work for finite periods, in the absence of an extreme situation, no stimulus prompted a sympathetic adrenal medullary or cortical response.

Circadian rhythms can influence mood and, therefore, must be considered when evaluating subjective mood. Generally, alertness occurs in the mornings and early afternoon; fatigue increases in the late afternoon and evening. In this study, only 4 of the 11 flights began outside of normal waking hours (0600-2200) or endured into the time for normal sleeping hours. Although mission start times varied, stress-fatigue responses did not appear to be

affected by circadian periodicity as noted by the trends of all physiologic and psychologic measures. Similarly, others have reported (9,21) that physiological stress is indifferent to short (4/4 h) or (16/16 h) work-rest cycles. We used 15/12 h work-rest cycles and believe that changes in moods inflight resulted more from differences in the intensities of the missions rather than circadian effects. Although no crew was intentionally deprived of sleep during this study, takeoff times varied for each mission, depending on operational needs. Thus, circadian rhythms may have influenced subjective mood scores for some missions.

In this study, changes in subjective-fatigue scores over flight times also differed from other studies of long-duration missions using the SAM Form 136 (12,16,21,22). Others have reported that subjective fatigue is higher with increased work loads because of the nature of the mission and the position of the crew member (21). In our study, crew members' fatigue scores for each flight were averaged by times; we did not analyze the responses by task. Nonetheless, P-3 crews consist of personnel with various specialized jobs requiring intense concentration and activity at different times during a mission. A stressful period for one crew member may or may not coincide with equally intense periods of other crew members.

Sleep quality and quantity were not evaluated and may have also contributed to the initial (preflight) severe fatigue scores. One might argue that the rising trend to alertness postflight may have been a reflection of mood shifts due to the completion of the mission, but our positive and negative-mood scores contradict that theory. In most cases, positive mood declined, and negative mood became greater sequentially during the mission.

Grip-strength measurements for right and left hands showed inter- and intracrew variability that were not consistent. The inflight strength data were inconclusive and suggest possible noncompliance by crew members, who failed to produce maximal voluntary contractions when measured. Individual compliance may have been a factor; however, sequential changes in right-hand (dominant for our subjects) strength over time agree with similar changes in left-hand strength for some crews and flights. Muscle strength and endurance are affected by fatigue and may be useful indicators of the physiologic cost of long-duration missions in a more controlled design.

Pre- and postdeployment physiological test results presented a complicated description of the crews that merits further investigation. All subjects were within normal limits on all aspects of the battery. This was expected as they were all young, healthy, asymptomatic naval crew members. Aerobic capacity tests indicated a decrease in cardiorespiratory fitness, possibly due to a lack of participation in endurance-enhancing activities during deployment. Resting cardiovascular measurements verified these findings, except for an unexplained decrease in resting HR. Although lung capacity increased, we attribute it to improved performance of the test instead of an actual improvement in lung function, which is unlikely.

Blood chemistry analyses suggested the 6-month deployment caused non-hematological deficiencies, except for increased serum lipid concentrations possibly due to a reduced amount of regular exercise accompanied by a richer diet. Muscular endurance of the legs improved but strength decreased, while grip strength improved after deployment. Surveys taken at the time of post-deployment testing explained that participation in regular physical activity

did not increase or decrease during the time away from home, further confounding these findings.

The U.S. Navy P-3 crews flying 12-h SUSOPS missions during a 6-month overseas deployment showed varying levels of stress and fatigue, which did not appear to compromise performance or safety. The 15-h nonflying intervals between flights seemed to be sufficient and did not impose extreme psychophysiological stress on the crews. Current Navy requlations governing work/rest cycles (15h rest/12h work) appear to be non-prohibitive.

## RECOMMENDATIONS

We recommend that future investigations of ASW SUSOPS in the patrol community include sleep surveys, body temperature monitoring, and crew task-performance assessment, which were not addressed in this study. When considered with the physiological and psychological parameters that we evaluated, additional research may yield answers to the problems of how to better define and measure fatigue, performance, and the effect of fatigue on performance. Sacrificing the completion of a mission because of crew fatigue is not a viable alternative but future research can reduce the risks and effects of fatigue on flight performance.

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None are applicable.